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Watershed scale temporal and spatial stability of soil moisture and its role in validating satellite estimates

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Abstract

Watershed scale soil moisture estimates are necessary to validate current remote sensing products, such as those from the Advanced Microwave Scanning Radiometer (AMSR). Unfortunately, remote sensing technology does not currently resolve the land surface at a scale that is easily observed with ground measurements. One approach to validation is to use existing soil moisture measurement networks and scale these point observations up to the resolution of remote sensing footprints. As part of the Soil Moisture Experiment 2002 (SMEX02), one such soil moisture gaging system in the Walnut Creek Watershed, Iowa, provided robust estimates of the soil moisture average for a watershed throughout the summer of 2002. Twelve in situ soil moisture probes were installed across the watershed. These probes recorded soil moisture at a depth of 5 cm from June 29, 2002 to August 19, 2002. The sampling sites were analyzed for temporal and spatial stability by several measures including mean relative difference, Spearman rank, and correlation coefficient analysis. Representative point measurements were used to estimate the watershed scale (~25 km) soil moisture average and shown to be accurate indicators with low variance and bias of the watershed scale soil moisture distribution. This work establishes the validity of this approach to provide watershed scale soil moisture estimates in this study region for the purposes of satellite validation with estimation errors as small as 3%. Also, the potential sources of error in this type of analysis are explored. This study is a first step in the implementation of large-scale soil moisture validation using existing networks such as the Soil Climate Analysis Network (SCAN) and several Agricultural Research Service watersheds as a basis for calibrating satellite soil moisture products, for networks design, and designing field experiments.

Keywords: Soil moisture; Temporal and spatial stability; Advanced Microwave Scanning Radiometer

1. Introduction

Satellite soil moisture products are being developed using data from new sensors such as the Advanced Microwave Scanning Radiometer (AMSR) on the Aqua platform. These products (Njoku et al., 2003) will be the basis for longer term observation of the earth surface. Improved sensor systems are anticipated within the decade. The calibration of algorithms and validation of products are of vital importance at this stage in the development of the technology.

For soil moisture, two factors make validation extremely difficult. The first is a mismatch in scale between satellite footprints (>10 km) and a ground sample (~ 5 cm). The second is high spatial variability of soil moisture, which is influenced by various land surface and meteorological factors at different scales. Both factors necessitate a large number of distributed observations within a footprint to accurately estimate the average. The issues described above lead to the conclusion that a large number of ground based in situ samples will be required to validate a single footprint. It would be difficult to provide such information for a large number of footprints. Two approaches have been used in the past. One is short-term intensive field campaigns such as SGP97, SGP99, and SMEX02 (Bindlish and Barros, 2002; Famigliette et al., 1999; Jackson et al., 1999). These provide reliable estimates but for a subset of physical and climate conditions. Another approach has been to use data from existing in situ networks. A problem with this approach is the density of the network. Most provide only a single point within a footprint.

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Soil moisture scaling theory (Russo & Bresler, 1980; Warrick et al., 1977) demonstrates that accurate estimates of a moisture field can be obtained using point observations; however, this requires extensive sampling over long periods of time (Chen et al., 1995; Kachanoski & De Jong, 1988; Vinnikov et al., 1999; Yoo, 2002). Geostatistical analyses, such as kriging (Burgess & Webster, 1980; Delhomme, 1979) and semivariogram analysis, also require a dense sampling network to adequately portray the spatial character of the soil moisture field which could then be used to estimate field scale soil moisture. Vachaud et al. (1985) first proposed a method of large-scale soil moisture estimation by establishing temporal stability in a 2000-m^2 grass field in Grenoble, France. This technique investigates the idea that a soil moisture field maintains its spatial pattern over time. If the pattern is demonstrated to be stable at long time scales, it is possible to use this pattern to an advantage. The mean of the field at a given time is compared to specific sampling sites within the field to identify locations with a small bias to the mean and a low variability in its relationship to the mean. Once a specific location in an area is demonstrated to accurately estimate the average soil water content for the region, it should be possible to use that point or a reduced number of points for future studies. Their study demonstrated that it is possible to conduct watershed scale soil moisture estimation simply and efficiently.

Grayson and Western (1998) extended this research to several additional small watersheds with significant relief ranging in size from 0.1 to 27 km^2. These included the Tarrawarra catchment (Australia), mostly dryland grazing, Chickasha (Oklahoma, USA), mostly pasture and winter wheat, and Lockyersleigh (Australia), mixed grazingland and woodland. Kachanoski and De Jong (1988) argued that spatial scales, such as the correlation length scale, must be considered in this type of analysis. Their study focused on a small grassland field in Canada. Mohanty and Skaggs (2001) continued this work by studying soil type, slope, and vegetation cover and how it affects spatio-temporal stability of grassland and winter wheat near Chickasha.

These previous projects were conducted over scales (<27 km^2) smaller than most satellite remote sensing technologies (100–2500 km^2). The scale of temporal stability must be established at larger scales (Kachanoski & De Jong, 1988), if this approach is to be successfully used in the validation of large-scale remote sensing products. Also, there is a need to extend this research to different surface types such as agricultural crops.

The study reported here estimates watershed scale (~ 100 km^2) soil moisture averages for the purpose of validating current remote sensing products by means of point to watershed scaling of in situ soil moisture sensors. Using three methods of statistical exploration, namely mean relative difference analysis, Spearman rank coefficients and correlation analysis, the temporal and spatial stability of soil moisture for a region can be assessed. For a given season of study, representative locations can be identified for future regional estimation, greatly reducing the complexity and operational costs of watershed and regional scale monitoring. Also, determining temporal stability for a region validates estimation and extrapolation of large-scale averages. This work focuses on a temporary sensor network that was installed during the Soil Moisture Experiment 2002 (SMEX02). This network was in place for two months during the summer of 2002 and serves as a model for additional watershed investigations planned as part of an AMSR validation project.

This investigation explores the potential of temporal stability theory in satellite based soil moisture validation. This may provide a means to effectively design sparse validation networks and may also provide a way to utilize existing in situ networks for validation. In addition, this project will investigate the intricacies of random point sampling for validation.

2. Study region

The intensive study region of SMEX02 was the Walnut Creek watershed and the surrounding area, located south of Ames, Iowa, which is on the order of 100 km^2. A Landsat Thematic Mapper (TM) grayscale image from July 1, 2002 is shown in Fig. 1 with the outline of the watershed. Corn and soybean dominate the land cover, with approximately 50% and 40%, respectively. The remaining 10% of the area's land cover is grains and urbanization. The intensive field campaign portion of SMEX02 took place from June 25 to July 12, 2002. As part of that experiment, 12 Stevens-Vitel Hydra probes[1] were installed in 10 study fields near flux towers, which were located throughout the area. The study fields were designed to capture a variety of land cover conditions within the watershed. It is anticipated that future studies will increase the number of study locations to permit a better estimate of the variability. These stations operated during the field campaign and continued until August 19, 2002 (Jackson & Cosh, 2003). This extended period of time allowed for a wider range of soil moisture patterns to be observed. There are also 21 rain gages located throughout the watershed.

The soil moisture probes measured the dielectric constant of the soil. From this, the volumetric soil moisture was computed using previously determined relationships (Campbell, 1990). Each probe was installed at a depth of 5 cm (with an effective measurement depth between 3 and 7 cm). Some extrapolation and estimation of the soil moisture profile will be necessary for application of this

[1] Mention of product names does not constitute an endorsement of this product.

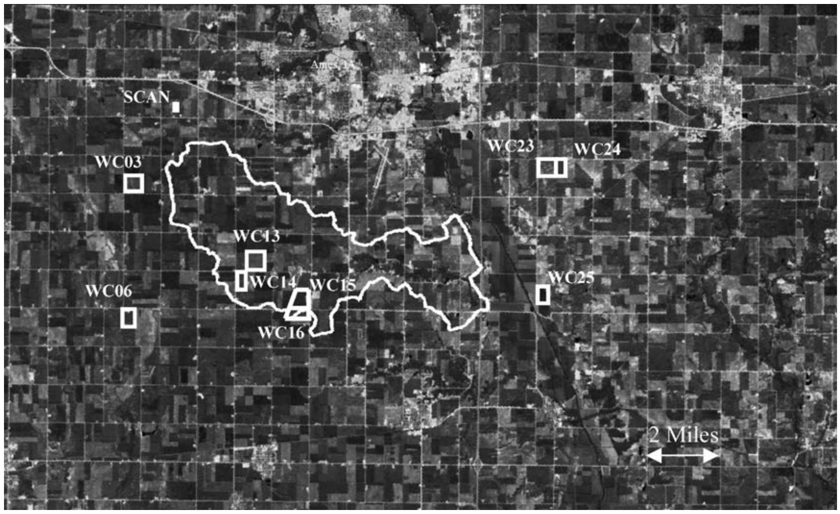

Fig. 1. An outline of the Walnut Creek watershed is shown over a grayscale TM image from July 1, 2002 (DOY 182) and each field site is indicated. The city featured in the top center of the image is Ames, IA. The center of the image is approximately 41.9676° latitude and −93.6350° longitude.

network to the variety of remote sensing technologies now available for sensing surface soil moisture (Jackson, 1993). Table 1 contains a listing of the watershed fields and operating periods for each sensor. Also included in this table is the crop type for each field. The soil texture in this region is predominantly silt loam and there was little different in the texture between sensor locations.

In addition to this temporary soil moisture sensor network, there is also a permanent soil moisture profiling station situated northwest of the watershed as part of the Natural Resources Conservation Service-Soil Climate Analysis Network (NRCS-SCAN) (Schaefer & Paetzold, 2001). This SCAN site records a suite of meteorological and hydrological variables, including precipitation, soil temperature, and soil moisture. Though the location of this particular site is in grass, which is uncharacteristic of the land cover in the region, the site was used in this study to evaluate its potential as a future tool for estimating the soil moisture in this region.

Table 1
Installation information for the soil moisture probe network installed in the Walnut Creek watershed near Ames, Iowa

Field	Latitude	Longitude	Install date (DOY 2002)	Removal date (DOY 2002)	Crop type
WC03	41.98017	− 93.73991	176	231	Soybean
WC06	41.93299	− 93.75338	178	231	Corn
WC13	41.97692	− 93.69126	178	231	Soybean
WC14	41.97460	− 93.69357	183	198	Soybean
WC15-1	41.95210	− 93.68774	176	224	Corn
WC15-2	41.94602	− 93.69611	176	231	Corn
WC16-1	41.93781	− 93.66466	176	231	Soybean
WC16-2	41.93779	− 93.66316	183	231	Soybean
WC23	41.93547	− 93.66411	177	186	Soybean
WC24	41.93417	− 93.66267	176	231	Corn
WC25	41.99252	− 93.53509	177	229	Corn
SCAN	41.01667	− 93.73333	(9/23/01)	Continuous	Grass

3. Method of analysis

Current estimation of watershed scale surface soil moisture requires a dense network of moisture probes located throughout the region to provide a large number of samples. The most efficient way of reducing this burden is to find a way to predict large-scale moisture averages from only a few sensors located at 'representative' sites. These sites can be identified through temporal stability analysis. If temporal stability can be established in a watershed, a small number of soil moisture sensor sites can be used to accurately and precisely predict watershed averages. This is accomplished by determining those sites that maintain a consistent temporal relationship with the watershed average with little variability.

The primary method for determining the temporal stability of a soil moisture field is the mean relative difference plot. This plot represents the ability of a particular soil moisture sensor location to estimate the average over the watershed. Building on Grayson and Western (1998) and Vachaud et al. (1985), this type of analysis was applied to the SMEX02 watershed network. The mean relative difference is defined as

$$\bar{\delta}_i = \frac{1}{t}\sum_{j=1}^{t}\frac{S_{i,j}-\bar{S}_j}{\bar{S}_j} \tag{1}$$

where $S_{i,j}$ is the jth sample at the ith site of n sites within the study region. $\bar{S}_j$ is the computed average among all sites for a given date and time, j (j = 1 to t). This variable directly measures how a particular site compares to the average of a larger region, whether it is consistently greater or less than the mean and how variable is that relationship. The mean relative difference of each site is then plotted by rank with error bounds of one standard deviation of the relative differences to determine which site best estimates the mean of the watershed. There are two criteria for selecting the ideal site for watershed estimation. Proximity of a site's mean relative difference to zero indicates it can accurately estimate the watershed average and small standard deviations (narrow error bars) indicate low variance of that estimate. If a site has both of these characteristics, it can be concluded that it accurately and precisely predicts the average watershed soil moisture for long time periods.

It is also important to assess the spatial stability of the soil moisture field that can be accomplished with the Spearman rank coefficient. This coefficient measures the correlation of site rankings from one day to the next, therefore assessing the spatial stability of the soil moisture distribution across the area of study (watershed). It is defined by

$$r_s = 1 - \frac{6 \times \sum_{i=1}^{n} (R_{i,j} - R_{i,j'})^2}{n(n^2-1)} \tag{2}$$

where $R_{i,j}$ is the rank of the soil moisture, $S_{i,j}$, at location i on day j, with a total of n days (Vachaud et al., 1985). $R_{i,j'}$ is the rank of the same location i for day j' when the sites are ranked in order from dry to moist, and assigned a number. A value for r_s near one indicates a stable soil moisture field, while r_s values near zero indicate a lack of stability. More simply, in a stable moisture field, the wet areas are always the most wet and the dry areas are the most dry. In an unstable moisture field, the sensors will be randomly sorted and there will be no consistency of wet and dry for any particular event. Therefore, a r_s of one is computed for pairs of days which maintain the same ranking among the soil moisture gaging sites. When dealing with an in situ network, it is necessary to address the temporal resolution. For most purposes, it is only necessary to consider soil moisture from one day to the next. Therefore in this analysis, the Spearman rank coefficient is calculated between each hour of each day (to account for any diurnal pattern in the signal) and then these are averaged together for a single coefficient for each day.

Another method of assessing spatial stability is the correlation coefficient (Chen et al., 1997). A correlation coefficient measures the relationship between two samples and is defined for these purposes by

$$r_{j,j'} = \frac{\sum_i (S_{i,j} - \bar{S}_{\cdot,j})(S_{i,j'} - \bar{S}_{\cdot,j'})}{\sqrt{\sum_i (S_{i,j} - \bar{S}_{\cdot,j})^2}\sqrt{\sum_i (S_{i,j'} - \bar{S}_{\cdot,j'})^2}} \tag{3}$$

where $S_{i,j}$ and $S_{i,j'}$ are soil moistures for a sampling site for a given time j and j'. The average soil moisture for that time across all sampling points is $\bar{S}_{\cdot,j}$. The resulting coefficients compute the correlation of the soil moisture pattern from one day to the next. It is expected that closely correlated patterns have a $r_{j,j'}$ near one, while uncorrelated patterns are indicated by $r_{j,j'}$ values near zero.

4. Results

Fig. 2 shows the time series of surface soil moisture measurements for the Walnut Creek watershed. This plot shows the average soil moisture across the watershed as calculated by the 12 sensors with one standard deviation error bars. Also plotted is the average cumulative precipitation recorded at rain gages throughout the watershed. Applying Eq. (1) to the data set resulted in a mean relative difference plot, shown in Fig. 3. Several key results can be drawn from this plot. WC06, a corn field in the southwestern corner of the watershed, had a mean relative difference close to zero and a small standard deviation, indicating a close correlation between the WC06 soil moisture at 5 cm and the expected average of surface soil moisture across the entire watershed region. This figure illustrates that the watershed contains many sampling locations which are stable in time, indicating the watershed is temporally stable.

It is apparent from Fig. 3 that there was little or no deterministic relationship between mean relative difference and crop type, because soybean and corn fields are scattered across the mean relative difference plot. This would indicate that there are other characteristics that may play a greater role in the selection of a representative site than does the land cover type, including location within the watershed, soil type, and topography.

Patterns are visible in Fig. 3 when the location of each site is considered. WC23, WC24, and WC25 are all located in the eastern portion of the study region and had smaller precipitation amounts. This is concluded from the negative mean relative differences for these sites. Negative mean relative differences indicate that the average at that particular site is less than the average across the whole region. Also, there was a small precipitation event on Day of Year (DOY) 185. The rain pattern was heterogeneous across the watershed; therefore, each site received a different amount of rainfall with some sites not receiving any rain at all. This resulted in moisture patterns were different from those of a large-scale event, thereby nullifying any temporal stability. Table 2 contains a listing of cumulative rainfall for DOY 185 as well as for DOY 191. On DOY 185, the distribution of rainfall was heterogeneous and non-saturating. This issue proves to be a problem for watershed scale estimation for particular time periods. Precipitation events occur on two scales: watershed scale and larger. It is expected that larger scale saturating events, such as DOY 191 in Table 2, will dominate the moisture field of a watershed at long time scales, but for any small time period, there could be an influence of small heterogeneous precipitation events. For large-scale saturating events, the moisture pattern is a result of the characteristics of each

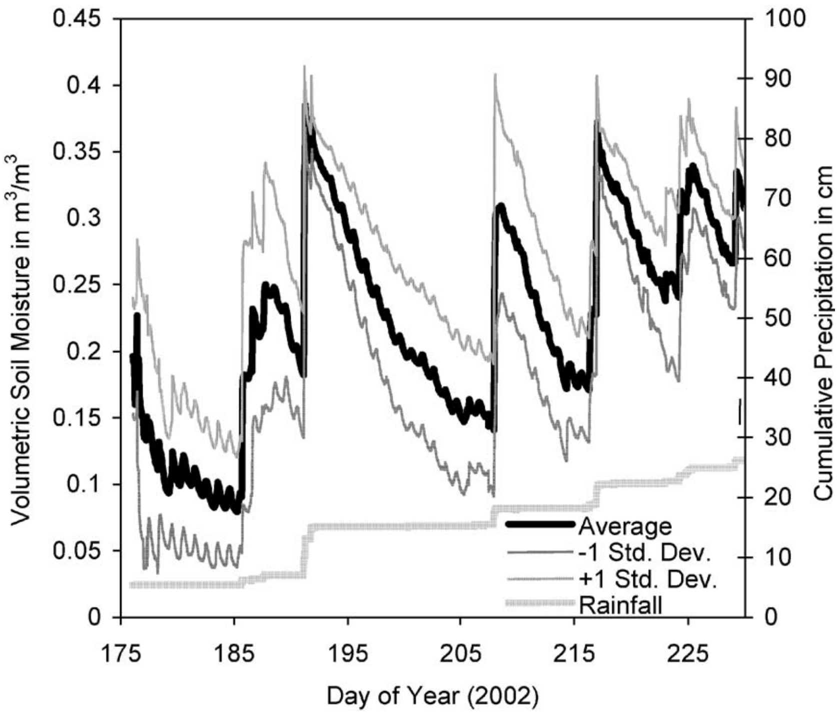

Fig. 2. Time series of surface (5 cm) soil moisture for each soil moisture probe in and around the Walnut Creek watershed. The average for each time step is also plotted in bold.

study site and not reliant upon the specific rainfall patterns of the precipitation event. Therefore, using a reduced number of point estimates to approximate watershed scale soil moisture should only be considered for long-term validation. For instance, the SCAN site had a significant amount of bias (nearly 20%) to the regional soil moisture average. This is determined from the large mean relative difference observed in Fig. 3. However, there is still potential to use the SCAN site as a rough approximation if this bias can be taken into account.

A closer examination of the temporal stability of precipitation was conducted using the 21 rain gages located in the watershed. Fig. 4 contains the correlation coefficient plot between the 21 rain gages, which recorded precipitation

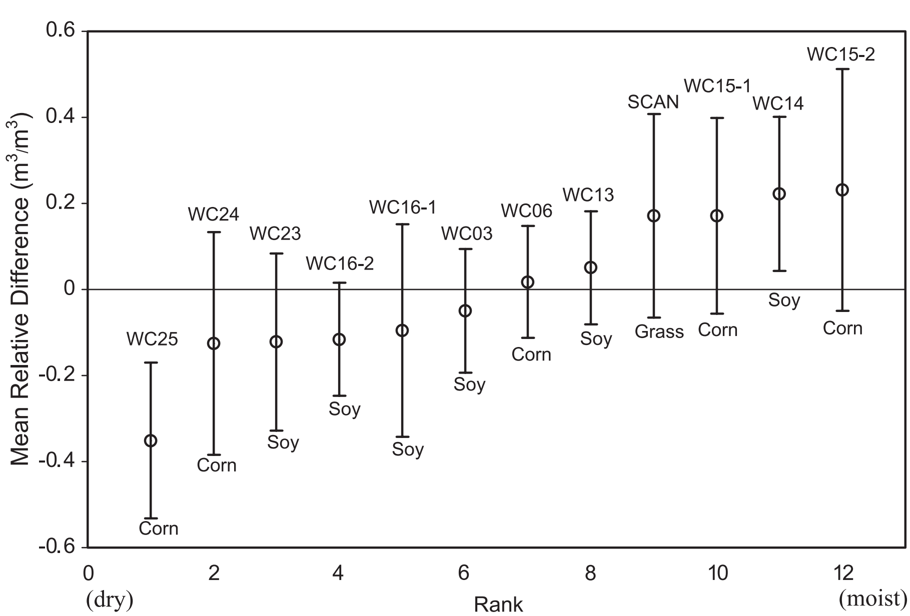

Fig. 3. The mean relative difference plot for the SMEX02 soil moisture network. Corn fields are labeled ‘Corn’, soybean fields are labeled ‘Soy’, and grassland is labeled ‘Grass’. The error bars are ± 1 S.D.

Table 2
Cumulative precipitation for two days during the study period

Rain gage	Latitude (WGS84)	Longitude (WGS84)	DOY 185 (precipitation in cm)	DOY 191 (precipitation in cm)
701	41.96432	− 93.68460	0.46	3.26
702	41.95425	− 93.64049	0.02	2.88
703	41.97925	− 93.65822	0.00	2.83
704	41.96503	− 93.65278	0.00	2.78
705	41.93686	− 93.65918	0.21	2.90
706	41.95054	− 93.65836	0.06	3.04
707	41.95056	− 93.67885	0.49	2.96
708	41.95058	− 93.69771	0.70	3.06
709	41.95062	− 93.71707	0.86	2.80
710	41.96446	− 93.71718	0.78	3.06
712	41.97957	− 93.69820	0.98	3.13
713	41.99405	− 93.71749	0.66	3.47
714	41.96776	− 93.69810	0.86	3.80
719	41.95779	− 93.59460	0.23	4.09
720	41.96332	− 93.61141	0.50	4.38
721	41.93567	− 93.58562	0.00	3.85
722	41.96285	− 93.57964	0.00	3.80
723	41.93923	− 93.56518	0.00	3.46
724	41.94694	− 93.60525	0.18	3.69
725	41.95373	− 93.62397	0.42	4.00
727	41.96504	− 93.67930	0.25	3.23

intensity during the study period. In this region, precipitation records are dominated by periods of no precipitation, which would bias the analysis toward being stable. Therefore, to remove this bias, only time periods that had precipitation at one or more rain gages were considered. Fig. 4 reveals that some rain gages are highly correlated while others are not. This indicates that the region is not temporally stable with regards to precipitation and heterogeneous at long time scales, which is to be expected at this spatial scale. This would lead one to believe that soil moisture must be unstable at long time scales. However, precipitation is partitioned into runoff, evaporation, and soil moisture, thus the conclusions drawn about soil moisture stability may still be reasonable.

A Spearman rank analysis determined that for most of the study period there is a strong spatial stability across the region. Fig. 5 shows a plot of these coefficients over time as well as a plot of the average soil moisture for the watershed, which is triangular by its nature. The average soil moisture values indicate when there is precipitation somewhere in the region. Fig. 5 is grayscale; therefore, the lighter the pixel, the higher the Spearman rank coefficient. Dark pixels indicate low values and time instability. For several time periods, there is a distinct lack of stability, such as for the days proceeding days 185, 208, and 223. Each of these periods follows a heterogeneous precipitation event, as shown by the drastic changes from high to low Spearman rank coefficients. Conversely, on day 191, there was a watershed scale rain, which affected each of the probe sites uniformly. Overall, the plot indicates that there is a persistent pattern to the watershed moisture condition such that for a given homogeneous precipitation event, there is a ranking among the surface soil moisture measurement sites. This spatial stability should prove useful for the summer-

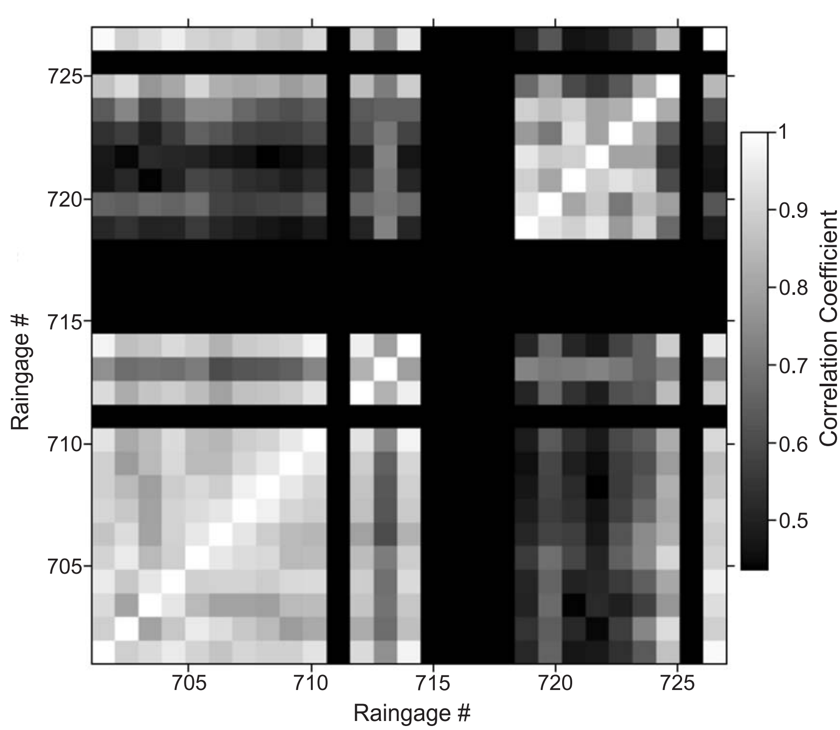

Fig. 4. A correlation coefficient plot for time periods of precipitation during the study. Light pixels indicate high correlation, while dark pixels indicate low correlation. Some rain gages were not in operation during the experiment, namely, 711, 715–719, and 726.

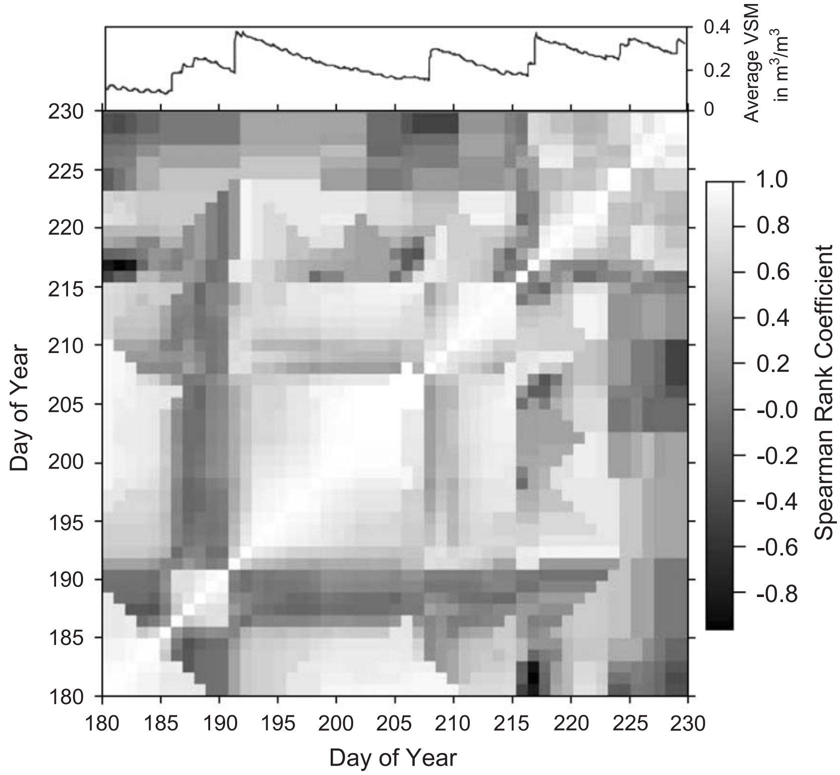

Fig. 5. Spearman rank coefficient plot of volumetric soil moisture by day of year (triangular matrix). Also included is a plot of the average soil moisture for the watershed for the same time period. Coefficients near one indicate strong rank correlation between the dates.

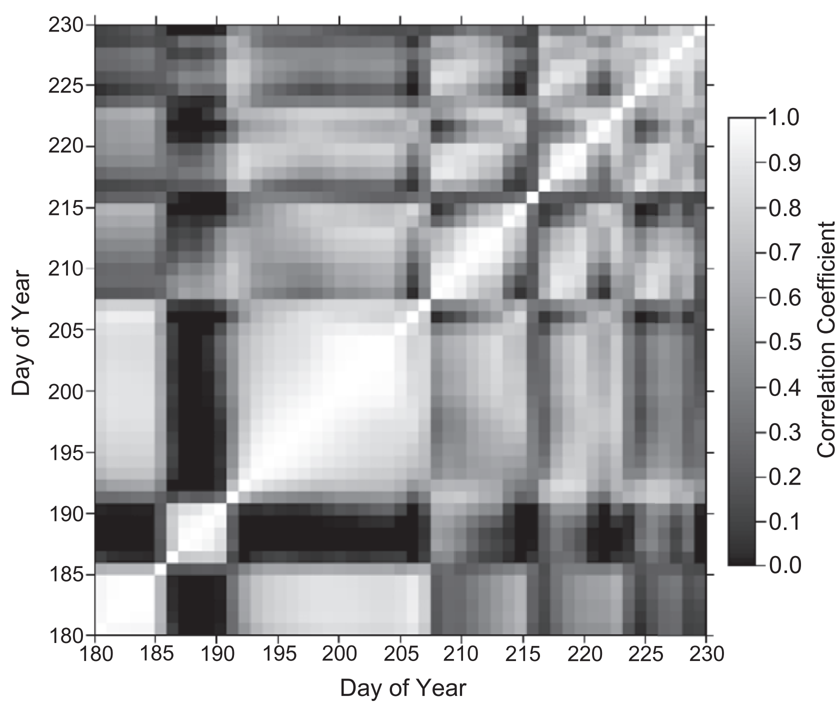

Fig. 6. Correlation coefficients plot of volumetric soil moisture by day of year (triangular matrix). Coefficients near one indicate strong rank correlation between the dates.

time prediction of watershed scale soil moisture with a sparse array of in situ soil moisture measurements.

Correlation analysis revealed a pattern similar to that of the Spearman Rank analysis. A plot of the correlation coefficients for the study period is shown in Fig. 6, and it is observed that it is nearly identical to Fig. 5. High correlation coefficients (demonstrating spatial stability) are indicated by white pixels, and low coefficients by dark pixels. Indeed, the same characteristic of strong correlations following a homogeneous rain event and weak correlations following heterogeneous events indicate that these two analyses point to the same conclusions. Point measurement estimation of watershed scale soil moisture is effective and appropriate for moisture conditions that are a result of precipitation events larger than the watershed scale. This analysis is supportive of the Spearman rank coefficient analysis, but for most circumstances only one is necessary.

Site selection was examined in greater detail to try and identify characteristics that make particular sites representative of the watershed. Initial considerations would reveal that closeness to the center of the region of study is not a necessity, because both WC03 and WC06 have low mean relative differences and are the western most sites. Land cover type alone did not appear to be a significant factor because there was no apparent link between soybean, corn, and mean relative difference rank, as shown in Fig. 3. There is a complex set of variables, including topography and soil type, which appear to affect mean relative difference (Mohanty & Skaggs, 2001).

Further investigation into the sensors within the watershed demonstrated how watershed scale estimation could be achieved by studying temporal stability. Locations that have

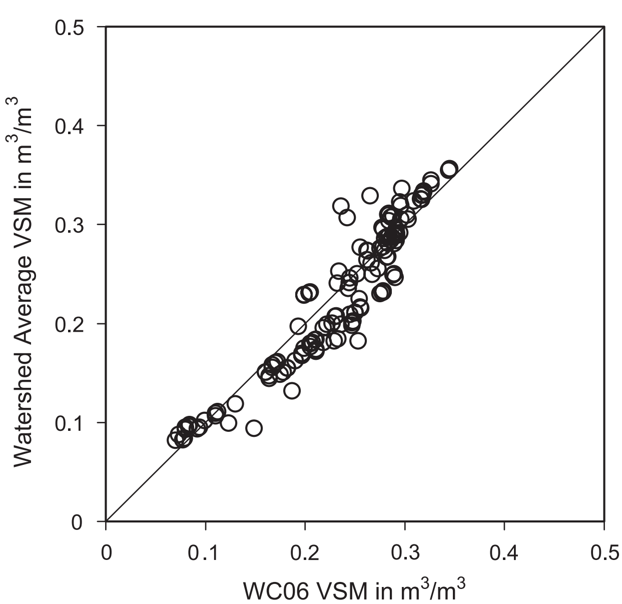

Fig. 7. A plot of WC06 VSM versus the watershed average (based on 12 soil moisture gages). The statistics for this plot are $R^2 = 0.846$, RMSE = 0.029, bias = 0.002.

Table 3
Regression statistics for predicting soil moisture average based on a single point measurement for the summer of 2002

Field	Bias (m^3/m^3)	R^2	RMSE (m^3/m^3)
WC03	− 0.010	0.856	0.032
WC06	0.002	0.846	0.029
WC13	0.014	0.895	0.030
WC14	0.041	0.974	0.044
WC15-1	0.031	0.685	0.054
WC15-2	0.041	0.689	0.058
WC16-1	− 0.009	0.923	0.040
WC16-2	− 0.027	0.828	0.040
WC23	− 0.017	0.297	0.042
WC24	− 0.018	0.849	0.047
WC25	− 0.076	0.785	0.085
SCAN	0.030	0.714	0.052

high bias values and poor RMSEs, such as the SCAN site and WC25, prove to be unstable monitoring sites. The detection of these sites improves the ability of a network to efficiently estimate averages. Representative sites can also be identified. For example, Fig. 7 shows a plot of soil moisture from WC06, one such representative site, versus watershed average soil moisture for randomly selected sampling dates and times. Table 3 contains the summary statistics for each site compared to the average of the watershed. These statistics were based upon a random sampling of times. The strong correlation ($R^2 = 0.846$) and low root mean square error (RMSE = 0.029 m^3/m^3) for WC06 support the selection of this site. The bias was also quite small at 0.002 (m^3/m^3). Bias and RMSE are useful statistics for temporal stability analysis and are analogous to the mean relative difference plot. When using these statistics as criteria for site selection, several locations are identified as representative and useful for future estimation.

5. Conclusions

Watershed and regional estimates of surface soil moisture are necessary for a wide variety of hydrologic and climatologic studies. The most accurate method of estimation is to thoroughly gage the region of interest; however, this is often infeasible. Remote sensing provides an attractive alternative. However, these methods must be calibrated and validated. This work demonstrates that single point in situ measurements can be used to estimate area average values accurately if spatial and temporal stability can be established in the region of interest. This was demonstrated by a combination of mean relative difference analysis and Spearman rank analysis. It has been shown that for the Walnut Creek watershed the soil moisture pattern during the summer of 2002 was both temporally and spatially stable for uniform precipitation events. A mean relative difference plot established that with accuracy and precision, representative sites could be used to estimate the watershed soil moisture average (among the measured points) for long time periods that have conditions similar to those found in the summer of 2002. For time periods that are subject to small non-saturating heterogeneous rain patterns, this stability is reduced. When precipitation events do not cover an entire region, the ranking of sites is going to be different from when every site receives a significant amount of rainfall. Several points may be necessary to accurately characterize the soil moisture for specific time periods. Certainly, the use of one random in situ point would be a treacherous plan. For example, if the SCAN site were used as a representative point, there would be a significant amount of bias included. Fortunately, experiments such as SMEX02 permit the SCAN to be calibrated to the watershed average for long-term studies with similar climatic conditions. It is demonstrated that short-term field experiments may be an appropriate method for establishing temporal stability and calibrating in situ field sensors for various seasons.

For the purpose of validating remote sensing of surface soil moisture products in this region, the temporal scales are greater than the short episodes of heterogeneous precipitation often experienced in field experiments. Indeed, the time scales of validation span many seasons and a watershed's soil moisture distribution at this time scale is, on average, a result of large-scale weather systems. It can be concluded that for the purposes of validation, temporal stability is a valuable tool for accurate and precise estimation of mean soil moisture.

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